Microwave Protection of a Field Crop Against Cold*

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ABSTRACT

An open field application of radiant microwave energy against frost damage of a corn crop is described. A sectoral horn antenna was used to radiate 2.4 kW at a frequency of 2.45 GHz. The antenna was positioned on a 6 foot tower overlooking a 25 foot by 25 foot corn field. The four-month-old corn (4 to 5 feet high) was successfully protected for 60 hours against a mass of cold northern air moving at 5–19 mph with peak gusts of 28 mph. During the entire 60 hour freeze the minimum temperature was —6°C and the maximum temperature was —1°C. The average wet bulb air temperature for the freezing period was —3.3°C, and the average wind speed was 13 mph. A snowstorm covered the experimental site with about ½ inch of snow. The resulting snow cover on the plant leaves did not hinder the microwave protection. This suggests a low dielectric loss factor for snowflakes. A number of plants (about 10 per cent) were dead by the end of the 60 hour freeze. These plants were directly facing the prevailing wind directions (northeast and northwest). The other plants were fresh and green with a slight change in stature. The experiment was terminated 3 days after the freeze period by wind gusts of up to 42 mph, which toppled most of the corn stalks. It is suggested that the stalks were weakened by the frost in the lower layers where the top-directed energy did not fully penetrate. More work should be done on establishing accurate wind-temperature threshold protection intensities and on suitable microwave applicators for various crops. This experimental study has shown that field radiated microwave energy can be an effective frost protection agent.

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Introduction

The advantages of microwave energy as a frost protection agent have been enumerated and evaluated in a previous laboratory investigation (1). In this paper an experimental study on an open field corn crop attempts to evaluate the effectiveness of the microwave protection method in a natural environment. The experimental equipment was installed on September 19 and the first frost condition developed during the early morning hours of October 22 when a cold air mass moved through the experimental site. Below freezing temperatures lasted for 60 hours. This unexpected severe weather condition was accompanied by strong winds and a 0.6 inch snowfall. No radiation frost occurred during the waiting period.

Besides the present use of microwave energy for crop protection, mention has been made (3) of using microwave energy to accelerate crop production and at the same time produce healthier, hardier, and larger plant species. Other experiments (3, 4) have also shown the usefulness of microwave energy in a variety of farm drying processes. The extensive use of microwave energy in agriculture will increase the microwave equipment duty cycle and thereby decrease the capital investment per operation. Capital investment and unknown biological effects will be the main concern in large-scale agricultural usage of microwave energy.

Materials and Methods

The Choice of a Crop

Corn was chosen as the test crop because its rich foliage was the most promising in minimizing the problem of microwave leakage from the experimental site. The corn was sown in early July so that it would be tender and responsive to the autumn frosts. A 2.4 kW microwave source at 2450 MHz was considered adequate for the available 25 foot by 25 foot lot. The corn kernels were sown 9 inches apart in standard rows at 30 inch intervals. Hourly temperatures, wind speeds, and daily precipitation data were obtained from the Montreal International Airport Weather Station situated 5 miles from the corn field. Additional temperature measurements were also made at the experimental site.

The Microwave System

A 6 foot tower was situated in one corner (the northwest) of the square lot as illustrated in Fig. 1. The 2.5 kW microwave source was mounted on the tower's platform along with a sectoral horn antenna inclined at an angle of 12° from the horizon. A heat exchanger mounted beneath the tower's platform was used for cooling the magnetron and the 60 Hz power transformer. Electric power was supplied by a gasoline motor generator rated at 5 kW having multiple 220 V ac and 110 V ac single phase outputs.

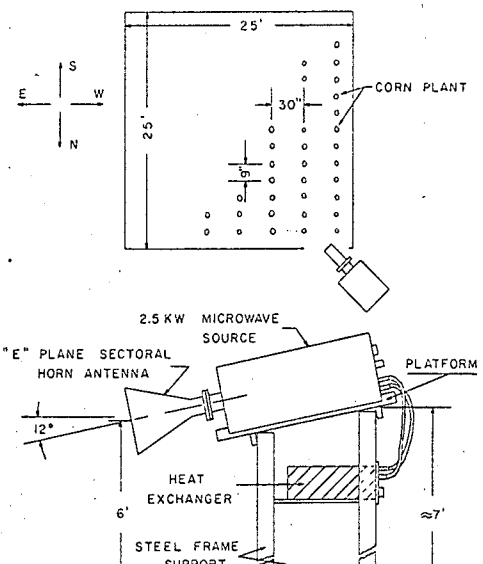

FIG. 1 An illustration of the microwave tower and corn field.

Microwave Radiation Intensity and Related Measurements

The design of the sectoral horn antenna used in this experiment is shown in Fig. 2. The field intensity of the beamed microwave energy was measured at different depths below the foliage level. The method of measurement is illustrated in the block diagram of Fig. 3. The design of the receiving corner reflector used in the

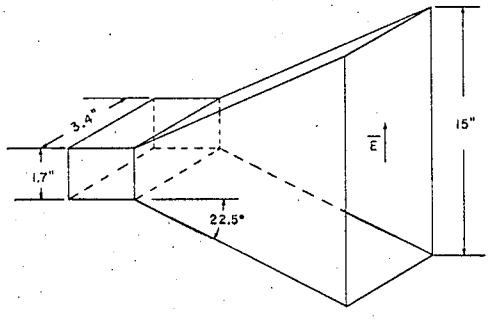

FIG. 2 The *E*-plane sectoral horn antenna. The beamwidth in the *E*-plane is 20°, and in the *H*-plane 80°.

above intensity measurements is shown in Fig. 4. Low-power radiation intensity levels were normalized relative to the high-power radiation intensity at a reference point in the corn plot. The results are given in Fig. 5 in the form of constant radiation intensity contours. A separate experiment showed that the attenuation is about ½ dB per linear foot of foliage penetration at a frequency of 2.45 GHz. Another experiment showed that the temperature rise in a plant leaf was 4°C in a region where the radiation intensity was 150mW/cm². The temperature measurement was made with a single copper-constantan thermocouple imbedded inside a plant leaf where the wind speed was 12 mph.

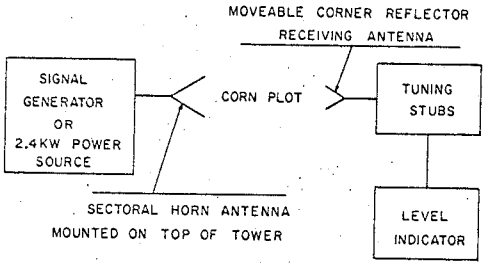

FIG. 3 An illustration of the radiation intensity measurement method.

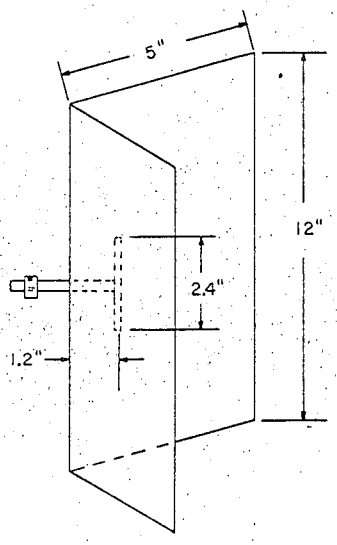

FIG. 4 The corner reflector antenna design.

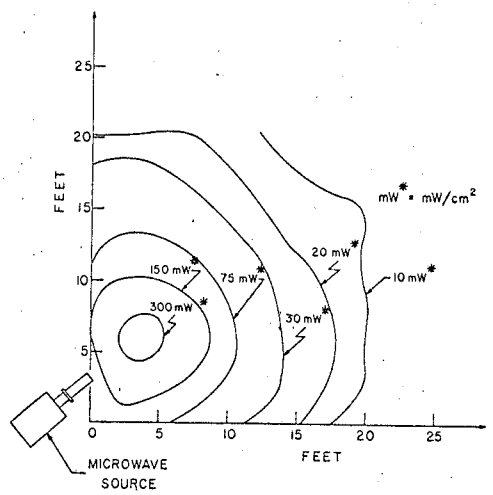

FIG. 5 Microwave radiation intensity measurement results obtained 4 feet above ground level. The total beamed microwave power was 2.4 kW. The leakage radiation intensity at distances of 10 feet outside the corn plot was less than 1 mW/cm² as measured with a Narda radiation monitor (B86B7).

Results of the Test Period

Table I presents the meteorological data obtained during the reported test period, which lasted from October 21 to 27. The microwave power was turned on 3 hours before freezing temperatures were reached. Figure 6 shows the corn plot 9 hours after the start of the freeze and at a time when the snowfall had reached 0.5 inch. Figure 7 was taken 31 hours after the start of the freeze, and Fig. 8 shows the corn crop 51 hours after the end of the 60 hour freeze period. During the warm-up period it had rained and this gave the corn leaves extra vigour and freshness as seen from Fig. 8. The mortality plot in Fig. 9 shows that the plants injured by frost were in a low radiation field or were facing the prevailing wind directions (northeast and northwest). In areas where the plants were not directly exposed to the wind the threshold radiation is estimated to be about 10 mW/cm². In regions exposed directly to the wind even high radiation intensities of 150 mW/cm² were not sufficient to protect the

TABLE I

HOURLY METEOROLOGICAL DATA SUPPLIED BY THE MONTREAL INTERNATIONAL AIRPORT WEATHER STATION SITUATED FIVE MILES FROM THE TEST SITE. SPOT CHECKS SHOWED CLOSE AGREEMENT BETWEEN THE AIRPORT TEMPERATURES AND THE SITE TEMPERATURES

WET BULB THERMOMETER TEMPERATURE (°F)

Date (Oct.) 1969	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
21	40	40	40	40	40	38	36	35	35	35	33	34	34	34	34	34	34	34	34	33	33	33	33	34
22	31	30	28	27	27	27	27	27	27	27	28	28	29	29	29	29	29	29	29	28	27	27	26	25
23	26	26	25	24	24	23	21	22	23	24	24	24	24	26	27	27	27	26	24	26	27	26	24	22
24	21	22	23	23	21	21	22	22	27	29	30	34	35	35	36	37	36	36	37	37	37	37	38	39
25	39	40	40	40	39	39	40	41	41	42	42	42	42	43	43	43	43	42	43	42	42	42	42	42
26	42	42	42	42	41	40	37	37	37	36	37	37	37	38	38	38	39	39	39	38	39	39	40	42
27	44	44	44	45	46	46	44	44	41	40	39	38	37	37	36	35	35	35	32	31	29	30	29	29

WIND DIRECTION AND SPEED (mph)

Date	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
21	NNE	C	N	C	NNE	NNE	NNE	NNE	NNE	NNE	NNE	N	N	C	SW	W	WNW	N	C	W	W	W	W	N
	2		4		7	9	11	7	12	11	10	5	7		3	6	4	2		3	7	10	4	4
22	ENE	ENE	ENE	ENE	NE	ENE	NE	NNE	NNE	NE	NE	NNE	N	N	N	N	N	NNW	N	N	N	N	NW	NNW
	12	16	12	12	11	11	11	10	15	14	15	15	11	11	13	12	8	6	8	10	9	8	8	10
23	NW	NW	NW	NW	WNW	WNW	WNW	WNW	WNW	WNW	NNW	NNW	NW	WNW	WNW	WNW	W	W	WNW	W	W	W	W	W
	12	10	12	11	10	13	10	10	14	19	15	15	13	18	19	17	16	13	9	13	17	13	12	7
24	W	W	WSW	WSW	WSW	WSW	WSW	W	W	WSW	W	WSW	WSW	WSW	W	WSW	WSW	SW	SW	SW	SW	SW	SW	SW
	7	8	8	9	6	6	5	5	8	10	15	10	15	15	12	19	14	16	16	13	20	18	18	16
25	SW	SW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	W	WSW	WSW	WSW	WSW	WSW	WSW	W	WSW	W	W	W	W	W	W
	15	16	12	9	14	10	9	8	10	8	10	8	8	8	7	5	6	6	8	10	7	8	6	6
26	WNW	WNW	C	WSW	N	NE	NE	NE	NE	ENE	ENE	ENE	ENE	NE	ENE	ENE	NE	NE	NE	NE	NE	E	E	SE
	1	1		3	6	10	8	10	8	8	7	7	8	7	10	8	6	8	6	6	4	2	2	6
27	SSE	SSE	S	SW	WSW	SW	SW	SW	W	W	W	W	W	W	W	W	W	WSW	W	W	WSW	WNW	W	WNW
	16	16	10	7	17	18	17	24	25	24	26	29	20	20	17	13	13	14	14	10	8	4	5	5

Peak gusts from October 21 to 27 were as follows: none, 22(NE), 28(NNW), 28(SW), none, 20(SSE), 42(W)

FIG. 6 A photograph of the corn crop 9 hours after the start of the freeze period. A layer of snow covered the plants during this period. The radiating antenna (not seen) is situated at the right of the picture.

FIG. 7 A photograph of the corn crop taken 31 hours after the start of the freeze period. The radiating antenna is seen at top right.

corn plants. The experiment was terminated 3 days after the end of the 60 hour freeze period when wind gusts of up to 42 mph bent over most of the corn stalks. It is believed that the corn stalks were weakened by the frost in the lower layers where the top-directed microwave energy did not fully penetrate.

FIG. 8 A photograph of the corn crop taken 51 hours after the *end* of the freeze period. The radiating antenna is seen at right of picture.

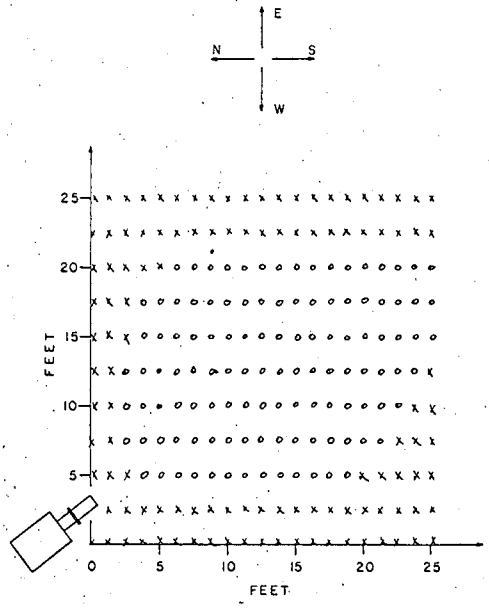

FIG. 9 The plant mortality diagram after the end of the 60 hour freeze period. The crosses indicate plants that were seriously damaged during the cold period. The prevailing wind directions were northeast and northwest.

Acknowledgment

We are grateful to Dr. Brawn of MacDonald College for providing the experimental site and other services from the McGill Experimental Seeding Farm in Ste-Anne de Bellevue, Quebec.

References

1 Bosisio, R. G., and Barthakur, N., "Microwave Protection of Plants from Cold," *J. Microwave Power 4* (3; Oct. 1969), 190–3.

2 Staff Report "Focal Points," *IEEE Spectrum*, November 1969, p. 28.

3 Boulanger, R. J., Boerner, W. M., and Hamid, M. A. K., "Comparison of Microwave and Dielectric Heating Systems for the Control of Moisture Content and Insect Infestations of Grain," *J. Microwave Power 4* (3; Oct. 1969), 194–208.

4 Sugie, R., Hirose, T., Oshima, K., and Amano, K., "The Characteristics of Microwave on Tobacco Shred," paper presented at the 4th IMPI Symposium, May 21–23, 1969, Edmonton, Alberta.

Bev Kumpfer, President of American Microwave Inc., has been asked by the Board of Governors to promote the Institute's aims and recommend its future course. As a result, publicity for the Institute's Symposium and objectives has increased. Members are asked to send ideas and suggestions to Bev Kumpfer.

IMPI's executive vice president Bev Kumpfer (American Microwave Corp, Salt Lake City)

Recent HEW Action Reviewed*

The wide press coverage of the announcement of the Secretary of Health, Education and Welfare, Robert H. Finch, on Monday, January 5, 1970, is a matter of considerable interest to the domestic, commercial, and industrial microwave industry. For the record, the HEW release is reproduced in its entirety here:

*Review received January 30, 1970.

HEW NEWS – FOR RELEASE IN A.M. PAPERS
Monday, January 5, 1970

Some microwave cooking ovens now used in homes and commercial establishments leak radiation which can present a health hazard to users, Health, Education, and Welfare Secretary Robert H. Finch said today.

Radiation levels in excess of the industry's voluntary standard of 10 milliwatts per square centimeter were detected in 51 of the 155 microwave ovens tested in a survey conducted by HEW's Consumer Protection and Environmental Health Service in cooperation with health agencies in four states, the Secretary said.

There have been no reports of injuries from the ovens, Secretary Finch said.

"This is a relatively new industry and we believe it is doubtful that any significant radiation damage has occurred," the Secretary said, "Many of the ovens have been in use for a short time and exposure is often brief and intermittent."

Secretary Finch said he has invited representatives from the microwave oven industries, a number of state health officials, and others to a meeting in Washington, D.C., on January 12, 1970, to discuss proposals for remedial action.

"There is a need," the Secretary said in his letter of invitation, "for a prompt survey of all microwave cooking ovens in use to identify the units with excessive microwave leakage in order that steps may be initiated to correct the defects."

Microwave ovens cook foods much faster than any other ovens, often in a matter of seconds. As many as 100,000 of the ovens are in use in the United States – about 40,000 of them in homes and 60,000 in hospitals, restaurants, and other establishments.

Until ovens now in use are checked, any deficiencies corrected, users should follow these precautions:

1 stay at least an arm's length away from the front of oven while it is on;